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METHOD AND APPARATUS FOR REDUCING EFFECTIVE TRACK WIDTH THROUGH HIGHLY SKEWED HEAD ANGLES

This application claims p~~P~~riority ~~is claimed~~ from U.S. Provisional ~~Patent~~ Application Serial No. 60/232,810, filed September 15, 2000 entitled "Reducing Effective Track Width Through Highly Skewed Head Angles," which is incorporated by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to ~~the field of~~ magnetic storage devices, and, more particularly, to ~~an apparatus and method for~~ increasing track density on a magnetic storage medium~~,~~ and increasing head width tolerance.

BACKGROUND OF THE INVENTION

A diagrammatic representation of a conventional disk drive~~, generally designated~~ 10~~,~~ is illustrated in **Fig. 1**. The disk drive 10 includ~~compris~~es a disk 12 that is rotated by a spindle motor 14. Digital information is stored within concentric tracks on the disk 12 which is coated with a magnetic material that is capable of changing its magnetic orientation in response to an applied magnetic field. The spindle motor 14 is mounted on~~to~~ a base plate 16. An actuator arm assembly 18 is also mounted on~~to~~ the base plate 16. The disk drive 10 also includes a cover (not shown) that is coupled to the base plate 16 and encloses the disk 12 and the actuator arm assembly 18.

The actuator arm assembly 18 includes a flexure arm 20 mounted on ~~attached to~~ an actuator arm 22 and a~~. A~~ head 24 is mounted on ~~near~~ the end of the flexure arm 20

opposite the actuator arm 22. The head 24 is constructed to magnetize the disk 12 and sense the magnetic field emanating therefrom.

The head 24 can include a single read/write element~~,~~ such as an inductive read/write element for ~~use in~~ both reading and writing, or it can include separate read and write elements. Heads that include separate elements for reading and writing are known as "dual element heads" and typically include a magneto-resistive (MR)~~,~~ or giant magneto-resistive (GMR)~~,~~ read element ~~for performing the read function~~.

The actuator arm assembly 18 pivots about a bearing assembly 26~~7~~ that is mounted on~~to~~ the base plate 16. Attached to the end of the actuator arm assembly 18 opposite the head 24 is a magnet 28 located between a pair of coils 30. The magnet 28 and the coils 30 are commonly referred to as a voice coil motor ~~32~~ (VCM) 32. The spindle motor 14, the head 24 and the VCM 32 are coupled to ~~a number of~~ electronic circuits 34 mounted on~~to~~ a printed circuit board 36~~,~~ which provide~~comprise~~ the control electronics of the disk drive 10. The electronic circuits 34 typically include a read channel~~-chip~~, a microprocessor-based controller and a random access memory (RAM) ~~device~~.

The disk drive 10 typically includes a plurality of disks 12 and, therefore, a plurality- of corresponding heads 24 mounted on~~to~~ flexure arms 20 for each disk surface. However, ~~it is also possible for~~ the disk drive 10 may~~to~~ include a single disk 12 as shown in **Fig. 1**.

During operation of ~~a conventional~~ disk drive 10, the disk 12 is rotated at a substantially constant rate about a central axis at a center 38 of the disk 12 ~~at a substantially constant rate~~. To read data from or write data ~~on~~to the disk 12, the head 24 is placed above a desired track of the disk 12 while the disk 12 is spinning. Writing is performed by delivering a ~~write signal having a~~ variable write current to the head 24 while the head 24 is held close to the desired track. The variable write current~~signal~~ creates a variable magnetic field at ~~a gap portion of~~ the write element that induces

magnetic polarity transitions into the desired track. These magnetic polarity transitions constitute the stored data.

Reading is performed by sensing the magnetic polarity transitions on the rotating track with the head 24. As the disk 12 spins below the head 24, the magnetic polarity transitions on the track present a varying magnetic field to the read element. The read element converts the varying magnetic field into an analog read signal that is ~~then~~ delivered to the~~a~~ read channel for appropriate processing. The read channel converts the analog read signal into a properly timed digital signal that can be recognized by a host computer~~ system~~.

~~As mentioned above, the head 24 may be a single element head or a dual element head.~~ A particularly important type of dual element head is an MR ~~magnetoresistive~~ head that includes an ~~magnetoresistive (~~MR~~)~~ read element and a separate write element that is usually inductive. MR read elements include a small piece of MR~~magnetoresistive~~ material having a variable resistivity that changes based on an applied magnetic field. That is, as the magnetic field applied to the MR material increases, the resistivity of the MR material, in general, decreases. In practice, the MR material is held near the desired track as a substantially constant sense current is run through the MR material. The magnetic field variations produced by the magnetic transitions on the rotating track change the resistance of the MR~~magnetic~~ material, resulting in a variable voltage across the MR material that is representative of the data stored on the disk (i.e., the analog~~a~~ read signal). MR read elements have gained much popularity in recent years as they typically generate analog read signals having considerably higher voltages than those generated by inductive read elements.

A more detailed view of the head 24~~a dual element head, generally designated 50, used for reading and writing magnetic polarity transitions to a magnetic media~~ is illustrated in **Fig. 2**. P~~Referring to the figure, p~~ortions of the ~~dual element~~ head 24~~50~~ which face towards the disk 12~~magnetic media~~ are shown. The head 24~~50~~ includes a

read~~write~~ element 40~~54~~, a read~~write~~ gap 42~~58~~, a first shield 44~~62~~, a second shield 4~~6~~6, a write~~read~~ gap 48~~70,~~ and a~~magnetoresistive (MR)~~ write~~read~~ element 50~~74~~. T~~It should be noted that t~~he write element 50~~54~~ ~~typically~~ has a width 52~~78~~ which is typically greater than a width 54~~82~~ of the read element 40~~74~~. For example, the width 52~~78~~ of the write element 50~~54~~ might be twice the width 54~~82~~ of the read element 40~~74~~. Furthermore, the read element 40 is an MR type. Thus, the head 24 is a dual element, ~~As is well known in the art, this illustrates a~~ "write wide/read narrow~~,~~" MR ~~type~~ head although t~~.—~~he present invention is applicable to ~~It will also be understood that~~ other types of heads~~ may be used~~.

When~~As part of the~~ writing~~ process~~, a variable write current is used to induce magnetic flux across the write gap 48~~58~~ between the write element 50~~54~~ and the first shield 44~~62~~. The write element 50~~54~~ and the first shield 44~~62~~ act as poles for an electromagnet which induces magnetic flux across the write gap 48~~58~~. The direction of the variable write current defines the direction in which the magnetic flux will be oriented across the write gap 48~~58~~. In some simple disk drive~~recording systems~~, flux polarized in one direction across the write gap 48~~58~~ will record a binary "one" on the disk~~magnetic media~~ while flux polarized in the opposite direction will record a binary "zero." In many other disk drive~~recording systems~~, a change in the direction that the flux travels across the write gap 48~~58~~ is interpreted as a "one" while the lack of a change is interpreted as a "zero." As~~ the magnetic material on~~ the disk ~~surface~~ 12 ~~(illustrated in Fig. 1)~~ travels under the head 24~~50~~ in the direction indicated ~~shown~~ by the arrow 5~~8~~6, a series of digital "ones" and "zeros" can be written within the ~~data~~ track.

When reading, the magnetic polarity transitions~~,~~ previously written ~~on~~to the disk 12 ~~magnetic media,~~ are coupled to the head 24~~50~~ in order to recover the stored digital data. When a magnetic polarity transition in the disk 12 ~~magnetic media~~ passes under the head 24~~50~~, the read element 40~~74~~ will generate an analog read signal in response to the changing magnetic field which corresponds to a previously recorded data bit. ~~This signal~~

~~is called an analog read signal.~~ Conversion of the analog read signal back into a digital signal is performed within the~~a~~ read channel, after which it is passed to an external~~ior~~ device~~environment~~ such as a host computer. During the read process, the first and second shields 44, 46~~62, 66~~ form the~~a~~ read gap 42~~70~~ which serves to focus the flux for a particular magnetic polarity transition onto the~~-~~ read element 40~~74~~ by shielding the read element 40~~74~~ from other sources of magnetic flux. In other words, extraneous magnetic flux is filtered away from the read element 40~~74~~ by the shields 44~~62~~, 46~~66~~.

D~~As is well known in the art, d~~ata storage capacity~~ies~~ in disk drives~~magnetic storage devices~~ is~~are~~ rapidly increasing. The~~is~~ increase in storage capacity is in large part due to ~~the~~ increased recording density on the disk~~magnetic media~~, allowing more data to be stored per unit area on the disk~~media~~. As the data density continues to increase, the number of tracks per inch (TPI) increases, resulting in ~~a~~ decreased track width for each track. In addition~~ to the increased TPI~~, the number of bits per inch (BPI) is also increasing.

The decreased track width impacts several areas of the disk drive~~magnetic storage device~~. One such area is the head. The width of the read and write elements ~~on the head~~ must be decreased in a similar manner as the track width~~,~~ in order to continue properly reading and writing data to and from the ~~data~~ tracks. However, due to limitations in the manufacturing technology used to fabricate ~~the~~ heads, it is becoming increasingly difficult to manufacture heads with read and write elements that have the required width. In ~~particular, as mentioned above, in~~ many heads, the width of the read element is less that the width of the write element. Thus, ~~in these type of systems,~~ it is often particularly difficult to fabricate the read element with~~to~~ the appropriate width.

For example, in one current ~~day~~ design, the read element has a nominal width of 0.14μ, with a tolerance of 0.04μ. When fabricating the~~a~~ read element, traditional semiconductor fabrication processes are used. However, current ~~day~~ photolithographic limits in the fabrication process are roughly the same as the nominal width of the read

element. Operating this close to the limits of the fabrication process can often result in heads which do not meet the nominal width and tolerance requirements~~ of the head~~. As a result, it is common practice to have the~~a number of~~ heads fabricated~~,~~ and then measure ~~the finished~~ ~~product in order~~ to determine which ~~of the~~ heads are acceptable. T~~As will be understood, t~~his can be ~~an~~ expensive~~ process,~~ due to ~~both~~ the time ~~required~~ to measure~~perform the testing~~ ~~of~~ the heads~~finished product,~~ as well as the cost of unusable~~the~~ heads~~ which are not usable due to being out of the specified limits~~. Accordingly, it would be advantageous to have a head width which is greater than the limits of the fabrication~~manufacturing~~ process~~,~~ while still meeting increased storage capacity demands~~in order to have a more robust manufacturing process for fabricating the heads~~.

Another area where reduced track width impacts the head is ~~in~~ the analog read signal~~ produced when reading data from the magnetic media~~. As a result of the reduced track width, and the resulting decrease in the read element~~er~~ width~~ as described above~~, the aspect ratio of the ~~MR~~ read element increases which in turn degrades the analog read signal.

______–Referring now to **Fig. 3**, a simplified cross-sectional illustration of the~~a~~ ~~MR~~ read element 40 is now described. The read element 40~~74~~ is positioned between two connecting leads 58, 60~~90, 94~~. A sense current is passed through the first connecting lead 58~~90~~, as indicated by the arrow 62~~98~~. The sense current then flows through the ~~MR~~ read element 40 (across the width 54)~~74~~, and then flows through the second connecting lead 60~~94~~, as indicated by the arrow 64~~106~~. The ~~MR~~ read element 40~~74~~ ~~is typically~~ includes~~comprised of~~ a soft adjacent layer (SAL), an insulating layer, and an MR sensor layer (not shown)~~, and is well known in the art~~. As a result of the biasing properties of the SAL, in combination with the sense current, the magnetization of the ~~MR~~ read element 40~~74~~ is deflected as~~, with this deflection~~ indic~~illustr~~ated by the arrow 66~~102~~. As the read element 40~~74~~ passes over the transitions recorded on~~into~~ the disk 12~~magnetic~~

~~media~~, the amount of the magnetization deflection i~~o~~n the read element 40~~74~~ is changed, changing the resistance of the read element 40~~74~~, thus either increasing or decreasing the voltage across the read element 40~~74~~, which is used to determine the data stored on the disk 12~~magnetic media, as mentioned above~~.

However, as the width 54~~82~~ of the read element 40~~74~~ decreases, the aspect ratio of the read element 40~~74~~ generally increases. The aspect ratio of the read element 40~~74~~ is the stripe height 68~~110~~ over the width 54~~82~~ of the read element 40~~74~~. In general, due to the decreased track width, the width 54~~82~~ ~~of the read element 74~~ decreases. However, as the width 54~~82~~ decreases, the stripe height 68~~110~~ is generally not reduced, resulting in an increased aspect ratio. The~~is~~ increased aspect ratio results in less magnetization deflection in the read element 40~~74~~, which ~~. This reduced magnetization deflection~~ in turn reduces the~~results in an~~ analog read signal~~ which is also reduced~~. Accordingly, it would ~~also~~ be beneficial to have the~~a~~ read element 40~~74~~ with ~~which has~~ a relatively low aspect ratio.

Furthermore, while an MR ~~type~~ read element has been described, similar problems are encountered with GMR ~~type~~ read elements. ~~As is well understood by those of skill in the art,~~ GMR ~~type~~ read elements employ additional structures to produce ~~a~~ fixed magnetization and ~~a~~ freely rotating magnetization. The analog read signal is ~~produced~~ based on the angle between the two magnetizations with increased aspect ratios resulting in a reduced angle between the two magnetizations. Thus, reduced aspect ratios would also be beneficial in GMR read~~type~~ elements~~ as well~~.

Another difficulty that arises from reduced track width is reduced magnetic flux from the magnetic transitions on ~~the surface of~~ the disk~~magnetic media~~. ~~As will be understood, the reduced track width results in reduced flux from the magnetic transitions.~~ The~~is~~ reduced flux ~~in turn~~ results in a decreased signal-to-noise ratio (SNR) in the analog read signal. Accordingly, it would also be beneficial to have ~~an~~ increased SNR with ~~a~~ reduced track width.

T~~As is known in the art, t~~he head skew angle is generally the angle of the read and write gaps relative to a radial line through the center of the disk. More specifically, the skew angle of the read element is the angle of a line parallel to the read element at the center of the read gap relative to a radial line through the center of the disk. Likewise, the skew angle of the write element is the angle of a line parallel to the write element at the center of the write gap relative to a radial line through the center of the disk. Generally, the difference in the skew angle of the read element and the skew angle of the write element is relatively small, thus the ~~term~~ head skew angle is used generally to cover both of these skew angles, with the understanding that the skew angles of the read element and the write element may be somewhat different.

______–Referring now to **Fig. 4**, an illustration of head skew in the~~a typical~~ disk drive 10 is now described. ~~As indicated in the figure, the disk surface 12 has a centerpoint 100.~~ The actuator arm assembly 18~~04~~ pivots about an actuator pivot 70~~112,~~ and has an arm length A (measured from the actuator pivot 70~~112~~ to either the center of the read gap or the center of the write gap). The distance from the center~~point~~ 38~~100~~ of the disk 12 to the end of the actuator arm assembly 18~~04~~ is the radius R. The distance from the center~~point~~ 38 of the disk 12~~100~~ to the actuator pivot 70~~112~~ is designated as M. The head skew angle θ at a radius R is ~~can then be~~ determined according to the following equation:

$$\theta(R) = \frac{\pi}{2} - \cos\left(\frac{A^2+R^2-M^2}{2AR}\right)^{-1} \qquad (1)$$

Typically~~, in current day disk drives,~~ the head skew angle ~~124~~ is minimized. This is the case for several reasons. One such reason is fly~~ing~~ height~~ concerns of the head~~. A t~~T~~ypical disk drives 10 ~~currently~~ has~~ve~~ the heads 24 fly very close~~ly~~ to the disk 12 ~~surface~~ at a distance known as the fly height. ~~The fly height is maintained by using an air~~

~~bearing, which is created when the disk spins beneath the head.~~ The head 24 is designed with an air bearing surface (ABS) which ~~acts to~~ maintains the correct fly height when the disk 12 is spinning. Traditionally, the~~is~~ ABS has been sensitive to the head skew angle ~~124~~, with increases in the head skew angle ~~124~~ resulting in a change in fly height compared to the fly height when there is zero head skew. Such a change in fly height, in general, is not desirable.

Furthermore, the head skew angle ~~124~~ has traditionally been minimized in order to enable ~~the~~ writing ~~of~~ radially coherent servo patterns~~information~~ to the disk ~~surface~~ 12 using the head 24. T~~In such systems, t~~he disk drive 10 may coupled to a servo track writer, which moves the actuator arm assembly 18~~04. The actuator arm 104 is used~~ to write the servo information. If the head 24 has a relatively high~~large~~ skew angle ~~124~~, it may be difficult to write a radially coherent servo pattern, resulting in a much longer servo write process ~~to write servo information~~.

As a result, head skew angles ~~124~~ have been minimized in traditional disk drive~~systems~~ 10. M~~, with m~~any disk drive~~products~~ 10 have~~ing~~ ~~a head with~~ a zero degree head skew angle ~~124~~ at about a midpoint 72~~126~~ between an inner diameter 74~~132~~ and an outer diameter 76~~128~~ of the disk ~~surface~~ 12. Such disk drive~~systems~~ 10 commonly have a change in skew angle of +/- 15 degrees as the head 24 is moved from the midpoint 72~~126~~ to either the inner diameter 74~~132~~ or the outer diameter 76~~128~~. Disk drive~~Products~~ 10 ~~are~~ also ~~known which~~ have a zero degree head skew angle at either the inner diameter 74~~132~~ or the outer diameter 76~~128~~, with the magnitude of the head skew angle increasing to about 20 degrees at the opposite diameter of the disk ~~surface~~ 12.

Accordingly, there is a need ~~to develop a method and apparatus~~ for (1) improving head ~~the~~ tolerances ~~of the head~~, thus allowing for narrower track widths with fewer heads rejected for not being within specifications, (2) reducing the aspect ratio of the read element, thus allowing for an enhanced analog read signal, and (3) increasing the SNR of the analog read signal.

SUMMARY OF THE INVENTION

The present invention solves the aforementioned problems and meets the aforementioned, and other, needs. The present invention provides a disk drive~~magnetic storage device~~ which employs a head with a high skew angle. This allows ~~the head to be designed such that~~ the head width to increase~~s~~ according to the inverse of the cosine of the head skew angle. In one embodiment, the head is mounted on the flexure arm at an angle~~, resulting in a minimum head skew angle across all of the data tracks on the disk surface~~. In another embodiment, the flexure arm is mounted on~~to~~ the actuator arm at an angle. In yet another embodiment, the length of the actuator arm assembly is shortened to allow a greater range of head skew angles across the~~a~~ disk~~-surface~~.

Additional features and other embodiments of the present invention will become apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation illustrating a disk drive;

Fig. 2 is a diagrammatic representation illustrating ~~the components of~~ a head in a disk drive;

Fig. 3 is a diagrammatic representation illustrating a read element in a head;

Fig. 4 is a diagrammatic representation illustrating ~~a component of a disk drive for the purpose of illustrating~~ head skew angles;

Fig. 5 is a diagrammatic representation illustrating a head in relation to a ~~data~~ track for a~~one~~ embodiment of the present invention;

Fig. 6 is a diagrammatic representation illustrating a skewed and non-skewed read or write element in relation to a ~~data~~ track for a~~one~~ embodiment of the present invention;

Fig. 7 is a diagrammatic representation illustrating a disk drive with~~and~~ an actuator arm assembly having a head mounted at an angle, according to an~~one~~ embodiment of the present invention;

Fig. 8 is a diagrammatic representation illustrating a disk drive with~~and~~ an actuator arm assembly having a flexure arm mounted at an angle, according to an~~one~~ embodiment of the present invention; and,

Fig. 9 is a diagrammatic representation illustrating a disk drive with~~and~~ an actuator arm assembly having a relatively short length, according to an~~one~~ embodiment of the present invention.

DETAILED DESCRIPTION

While this invention is susceptible of embodiments in many different forms, there are shown in the drawings and will herein be described in detail, preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspects of the invention to the embodiments illustrated.

Referring to **Fig. 5**, a diagrammatic illustration of the~~a~~ head 24~~200~~ in relation to a ~~data-~~track 78~~204~~ on the disk 12 in accordance with ~~of~~ an~~one~~ embodiment of the present invention is now described. In this embodiment, the head 24~~200~~ has a high~~large~~ skew angle 80~~208~~ with respect to the ~~data-~~track 78~~204~~. The high~~large~~ skew angle 80~~208~~ results in the~~a~~ read~~write~~ element 40~~212~~ and the~~a~~ write~~read~~ element 50~~216~~ being high~~which are also~~ly skewed with respect to the ~~data-~~track 78~~204~~. The~~is~~ high~~large~~ skew angle 80~~208~~ also results in the read element 40~~216~~ having an effective width 82~~220~~ with respect to the ~~data-~~track 78~~204~~ which is narrower than a~~the~~ physical width 84~~224~~ (width 54) of the read element 40~~216~~. Likewise, the write element 50~~212~~ has an effective width 86~~228~~ with respect to the ~~data-~~track 78~~204~~ which is narrower than a~~the~~ physical width 88~~232~~ (width 52) of the write element 50~~212~~. ~~In at least one embodiment, the skew angle~~

~~is zero degrees when the read element and the write element are located off of the data storage region.~~

Decreasing the effective widths 82~~220~~, 86~~228~~ of the read and write elements 40~~216~~, 50~~212~~ has several implications. First, the physical widths 84~~224~~, 88~~232~~ of the read and write elements 40~~216~~, 50~~212~~ may be increased relative to the track width 90~~236~~ of the track 78. The physical widths 84~~224~~, 88~~232~~ ~~of the elements 216, 212~~ increases according to one over the cosine of the high skew angle 80~~208~~. For example, the~~ head 200 may have a~~ high skew angle 80~~208~~ may be ~~of~~ 60 degrees. In such ~~a~~ case, the physical widths 84, 88 ~~224, 232 of the elements 216, 212~~ are ~~is~~ double the effective widths 82, 86~~220, 228 of the elements 216, 212~~. Thus, for a given track width 90~~236~~, the skewed read and write elements 40~~216~~, 50~~212~~ may have a larger physical width than ~~a~~ similar elements which are~~is~~ not skewed. A~~s can be understood, an~~ read or write element 40, 50 having a larger physical width is less difficult to manufacture than a~~n~~ read or write element 40, 50 with a smaller physical width. Likewise, the~~any~~ tolerance ~~required~~ for the read or write elements 40, 50 ~~216, 212,~~ is also increased according to the inverse cosine of the high skew angle 80~~208~~.

Referring to **Fig. 6**, a simplified illustration of this principle is now described. The ~~A data~~ track 78~~204,~~ with a centerline 92~~06~~ is illustrated, along with a zero-skew element 94~~240~~ (a read or write element) and a high-skew element 96~~24~~ (a~~4.~~ read or write element). The nominal width 100~~248~~ of the zero-skew element 94~~240~~ is illust~~ndi~~reated, along with a tolerance 102~~252~~ on either side of the zero-skew element 94~~240~~. The high-skew element 96~~244~~ has a nominal width 104~~256~~ which exceeds the nominal width 100~~248~~ of the zero-skew element 94 by the inverse cosine of the high skew angle 106~~258~~ of the high-skew element 96~~244~~. Likewise, the tolerance 108~~260~~ for the high-skew element 96~~244~~ exceeds the tolerance 102~~252~~ for~~of~~ the zero-skew element 94~~240~~ by the inverse cosine of the high skew angle 106~~258~~. Advantageously~~s discussed~~

~~above~~, increasing the element width and tolerance increases the margin of the element fabrication ~~manufacturing~~ process ~~used to fabricate the elements~~.

Referring again to **Fig. 5**, the ~~head 200 also includes a first shield 264 and a second shield 268. As alluded to in the Background of the Invention, the~~ read element 4~~21~~0~~6~~ reads magnetic signals present ~~in~~ between the shields 44~~264~~, 46~~268~~. The high skew angle 80~~208~~ also ~~results in~~ increases~~d~~ the effective shield spacing 110~~272~~ over the physical shield spacing 112~~276~~. The~~is~~ increased effective shield spacing 110~~272~~ ~~results in~~ increases~~d~~ the magnetic flux from the disk 12~~surface of the magnetic media~~ available to the read element 4~~head 21~~0~~6~~. This in turn ~~results in an~~ enhances the~~d~~ SNR for the analog read signal.

However, due to the increased effective shield spacing 110~~272~~, the width of a bit of data stored in the ~~data~~ track 78~~204~~ must also be increased as compared to the width of a bit of data stored in the ~~data~~ track 78~~204~~ with a low ~~hen the~~ skew angle ~~208 is substantially less~~. The width of a bit of data is commonly known as the pulse width~~, and is well known in the art~~. Accordingly, the pulse width in a disk drive ~~magnetic storage device~~ according to this embodiment is increased as compared to the pulse width of a disk drive~~magnetic storage device~~ with~~hich has~~ a lowe~~r~~ skew angle ~~208~~. However, the pulse width may be limited by the thermal stability of the ~~magnetic media~~disk 12. When the thermal stability limit is reached, the pulse width may not be reduced ~~any~~ further~~,~~ because the disk 12~~magnetic media~~ may lose ~~the~~ magnetic charge. When the thermal stability limits the reduction of pulse width, having an increased pulse width with a highly skewed head 24~~200~~ may be beneficial, as the disk 12~~magnetic media~~ will retain magnetic charge~~,~~ and the SNR for the analog read signal is enhanced as compared to a head 24 with ~~a~~ reduced skew angle.

The stripe height 68 is also ~~Another~~ effected by ~~of~~ the high~~increased~~ skew angle 80 ~~is the stripe height~~. ~~As discussed above in the Background of the Invention, it is beneficial to have a relatively low aspect ratio in an MR element. According to one~~

~~embodiment of the present invention,~~ Tthe aspect ratio of the ~~MR~~ read element 40 can be reduced by increasing the physical width 84 of the ~~MR~~ read element 40. This allows for a reduced aspect ratio when the stripe height 68 is not adjusted~~,~~ and the physical width 84 of the ~~MR~~ read element 40 is increased. Th e~~is~~ reduced aspect ratio allows for ~~a~~ larger magnetization deflection in the ~~MR~~ read element 40, and thus the ~~and an~~ read element 40 ~~which~~ is more sensitive to magnetic flux changes. Accordingly, the analog read signal produced by the ~~such an~~ read element 40 is enhanced. Additionally, the reduced aspect ratio ~~allows for an~~ increases~~d~~ the angle between the fixed magnetization and the freely rotating magnetization in a GMR read ~~type~~ element, resulting in an enhanced analog read signal.

T~~Furthermore, t~~he high~~increased~~ skew angle 80~~208~~ also ~~allows a~~ reduces~~d~~ the ~~effective~~ track width 90~~236~~ as compared to a ~~a data~~ track 78 which is not associated with ~~does not use~~ a highly skewed head 24~~200~~. B~~As mentioned above, be~~cause of the increased effective shield spacing 110~~272~~, the pulse width may be increased for a~~the~~ highly skewed head 24. Therefore, the reduced track width 90~~236~~ is offset by the increased pulse width, thereby resulting in ~~a net effect of~~ little or no storage capacity gain or loss for the ~~a~~ disk 12 in ~~magnetic storage device employing~~ this embodiment. However, the ~~as mentioned above,~~ thermal stability of the disk 12~~magnetic media~~ may limit the pulse width. Thus, ~~in an embodiment~~ where the pulse width is limited by the thermal stability of the disk 12~~magnetic media~~, the reduced track width 90~~236~~ can ~~result in an~~ increase ~~in~~ the storage capacity of the disk 12~~magnetic media~~.

Referring now to **Fig. 7**, ~~one embodiment is illustrated for giving a head a large skew angle. As can be observed,~~ the head 24~~300~~ is mounted on ~~at the end of~~ the flexure arm 20~~304~~ at a high mounting ~~n~~ angle 114~~306~~ relative to a centerline 116~~307~~ of the actuator arm 22~~308~~ in accordance with an embodiment of the present invention. In addition, t~~T~~he flexure arm 2~~3~~0~~4~~ is mounted on~~to~~ ~~the end of~~ the actuator arm 22~~308~~ at~~with~~ no significant angle relative to the centerline 116. As a result, the head 24 has a high

skew angle 118. For example, a high mounting ~~In one embodiment, the head 300 is mounted at an~~ angle 114 of 45 degrees ~~relative to the end of the flexure arm 304. This~~ produces a high skew angle 118 ~~316, in one embodiment, of approximately 45 degrees at the outer diameter 320 of the magnetic media 12, and a skew angle 316~~ of approximately 65 degrees at the inner diameter 7~~32~~4 and approximately 45 degrees at the outer diameter 76~~of the magnetic media 12. It will be understood that other angles 306 for mounting the head 300 on the flexure arm 304 are possible, resulting in different skew angles 316~~.

In this embodiment, ~~As will be understood by those of skill in the art, servo information which is written to the magnetic media is generally used to position the head 300 in the proper location relative to the surface of the magnetic media 12. This servo information can be written to the magnetic media 12 in a number of ways.~~ a ~~One such method of writing this servo information is to use a~~ servo track writer~~, which~~ coupleds to the actuator arm assembly 18 such that the head 24 writes servo information to the disk 12 ~~312 within the disk drive and writes a radially coherent servo pattern to the magnetic media 12. However, in the embodiment of Fig. 7, this method~~ will not produce a radially coherent servo pattern. However, ~~Thus, in using this embodiment, the above-noted method for writing servo information is not used. Rather, an alternative servo pattern, or method of writing the servo pattern, is used. One such alternative is to introduce~~ an alternate head ~~to the magnetic media, which~~ can ~~act to~~ write a radially coherent servo pattern. Similarly, a~~Another alternative is to use magnetic media which has a pre-printed~~ radially coherent servo pattern can be pre-printed on the disk 12. Likewise, ~~. Yet another alternative is to use~~ a spiral servo pattern can be used to self-write a radially coherent servo pattern as ~~, an example of which is~~ described in U.S. ~~Patent~~ Application Serial No. 09/853,093, filed ~~on~~ May 9, 2001~~,~~ entitled "Method and Apparatus for Writing and Reading Servo Information Written in a Spiral Fashion," which is incorporated herein by reference in its entirety.

Referring now to **Fig. 8**, ~~another embodiment for giving a head a large skew angle is illustrated. As can be observed from the figure,~~ the flexure arm 2~~3~~04 is mounted on ~~at the end of~~ the actuator arm 22~~308~~ at a high mounting ~~an~~ angle 120~~328~~ relative to the centerline 116 of the actuator arm 22 in accordance with an embodiment of the present invention. In addition, the head 24 is mounted on the flexure arm 20 at no significant angle relative to a centerline 122 of the flexure arm 20. This results in the head 24~~300~~ ~~at the end of the flexure arm 304 of the actuator arm assembly 312~~ having a high skew angle 124~~332~~. For example, a high~~In this embodiment, the head 300 is mounted such that it is tangential to the end of the flexure arm 304, and the flexure arm 304 is mounted at an~~ mounting angle 120 ~~328 with respect to the actuator arm 308. This~~ produces a high skew angle 124~~332, in one embodiment,~~ of approximately 65 degrees at the inner diameter 74 and ~~of~~ approximately 45 degrees at the outer diameter 76~~320 of the magnetic media 12, and a skew angle 332 of approximately 65 degrees at the inner diameter 324 of the magnetic media 12. It will be understood that other skew angles 332 are possible~~.

In this embodiment, a radially coherent servo pattern can be produced i~~I~~n a similar fashion as described for ~~to~~ the embodiment ~~described above with respect to~~ in **Fig. 7**~~, this embodiment also requires an alternative method of writing servo information to the magnetic media. Such alternatives include pre-printed media, introducing an alternate head to the magnetic media for recording the servo pattern, and a spiral type servo pattern, all of which were mentioned above~~.

Referring now to **Fig. 9**, a short ~~another embodiment for giving a head a large skew angle is illustrated. As can be observed, the~~ actuator arm assembly 126~~336~~ has a ~~in manufactured such that it is~~ relatively short length as compared to the ~~a typical~~ actuator arm assembly 18 (shown in phantom~~340 commonly used in current day devices and represented by the dashed lines~~) in accordance with an embodiment of the present invention. The ~~result of the~~ shorte~~r~~ actuator arm assembly 126~~336~~ results in ~~is~~ a relatively large difference in the ~~head~~ skew angle 128 between the inner diameter 74 and

the outer diameter 76~~320 and the inner diameter 324 of the magnetic media surface 12~~. For example, ~~As can be seen by the solid lines of Fig. 9,~~ the skew angle 128~~344~~ near the inner diameter 74 is approximately 60 degrees and near the outer diameter 76~~320~~ ~~in this embodiment~~ is approximately 20 degrees~~. As can be seen by the dotted lines of Fig. 9, the skew angle 348 near the inner diameter 324 of the magnetic media surface 12 is approximately 60 degrees~~.

In this embodiment, a servo track writer coupled to the short actuator arm assembly 126 such that the head 24 that writes servo information to the disk 12 can produce a radially coherent servo pattern.

Track misregistration is commonly higher toward the outer diameter 76 due to a number of factors such as disk flutter. Advantageously, by decreasing the skew angle as the head 24 moves from the inner diameter 74 to the outer diameter 76, the effective widths 82, 86 of the read and write elements 40, 50 increase as the head 24 moves from the inner diameter 74 to the outer diameter 76, thereby ~~the length of the actuator arm assembly 336 is selected such that the skew angle 344 near the outer diameter 320 is relatively low, with the skew angle 348 near the inner diameter 24 being relatively high. In this embodiment, these angles are selected to~~ minimizing~~e~~ track misregistration ~~track misregistration (TMR)~~ towards the outer diameter 76 where it is most problematic~~320 of the magnetic media 12. TMR is commonly higher toward the outer diameter 320 due to a number of factors, including disk flutter, which is well understood in the art. Thus, this embodiment results in an effective head width which is wider towards the outer diameter 320 than it is toward the inner diameter 324. Additionally, in this embodiment, the head 300 located on the actuator arm assembly 336 can continue to be used to record a radially coherent servo pattern on the surface of the magnetic media 12~~.

The above embodiments have been described with an~~using~~ MR heads~~ as an example~~. However, ~~it will be understood that the above would also apply to~~ other ~~types of~~ heads and read/write elements~~,~~ including GMR ~~type~~ heads may be used. Furthermore,

the skew angle can be zero degrees when the read element and the write element are located at a position off of the data storage region of the disk.

While an effort has been made to describe some alternatives to the preferred embodiments, other alternatives will readily come to mind to those skilled in the art. Therefore, it should be understood that the invention may be embodied in other specific forms without departing from the spirit or central characteristics thereof. The present examples and embodiments, therefore, are to be considered in all respects as illustrative and not restrictive, and the invention is not intended to be limited to the details given herein.

ABSTRACT

A disk drive provides ~~method and apparatus are disclosed which allow for~~ increased ~~disk drive head~~ read and write element widths and tolerances, ~~. The method~~ and ~~apparatus~~ also provides reduced ~~allows for~~ track widths ~~to be reduced~~. T~~In one embodiment,~~ the head with the read and write elements ~~is skewed to~~ has~~ve~~ a large skew angle relative to the~~a plurality of concentric~~ ~~data~~ tracks ~~contained~~ on ~~a surface of magnetic media within~~ the disk ~~drive~~. The skew angle reduce~~results~~ the~~in an~~ effective width of the read and write elements ~~being reduced~~. Based on this reduction in effective width, the physical width ~~or tolerance~~ of the read and write elements may be increased. Furthermore, the width of the ~~plurality of data~~ tracks may be reduced instead of, or in addition to, the increased~~ in~~ read and write element width ~~or tolerance~~.